CLAIMS

I claim:

1. A novel photovoltaic solar cell comprising:

at least one absorber layer, and

at least one doped window layer having at least two sub-layers, wherein the first sub-window-layer is adjacent the absorber layer and forms a desirable junction with the absorber-layer and wherein the second sub-window-layer is adjacent the first sub-window-layer and has high optical transmission.

2. The solar cell of claim 1, wherein the photovoltaic cell comprises an thin film silicon (tf-Si) alloy based solar cell including at one of amorphous silicon (a-Si:H) based solar cell, nanocrystalline silicon (nc-Si:H) based solar cell, microcrystalline silicon (μc-Si:H) based solar, polycrystalline silicon (poly-Si:H) based solar cell, or other combinations and mixtures.

3. The solar cell of claim 2, wherein the photovoltaic cell including at least one of a-Si:H, a-$Si_{(1-x)}Ge_x$:H and other combinations and mixtures.

4. The solar cell of claim 2 wherein the doped window-layer comprises a p-type layer or an n-type layer.

5. The solar cell of claim 2, wherein the doped window-layer is formed using vapor phase deposition.

6. The solar cell of claim 5, wherein the doped window-layer is formed using plasma enhanced chemical vapor deposition.

7. The solar cell of claim 5, wherein the desirable deposition conditions are achieved by varying parameters including at least one of the following: temperature, composition of gas mixtures, rf power, pressure, reactor geometry and dilution with gases such as hydrogen.

8. The solar cell of claim 7, where the sub-window-layer is a p-type layer.

9. The solar cell of claim 7, wherein the deposition parameter adjusted to achieve desirable semiconductor properties is temperature.

10. The solar cell of claim 1, having a conversion efficiency of about 10% or greater.

11. The solar cell of claim 1, further comprising a substrate selected from at least one of: glass, metal or plastic.

12. The solar cell of claim 11, further comprising a suitable transparent conductive oxide layer adjacent the second sub-window-layer.

13. The solar cell of claim 1, further comprising an encapsulation layer overlaying the solar cell to provide a substantially airtight and watertight protective barrier against moisture and contaminants.

14. The solar cell of claim 1, further comprising a buffer semi-conductor layer between the absorber-layer and the first sub-window-layer.

15. The solar cell of claim 4, wherein the first and second sub-window layers each comprise silicon-containing materials.

16. The solar cell of claim 15, wherein the absorber-layer comprises hydrogenated amorphous silicon germanium.

17. A method for manufacturing a solar cell comprising the steps of (i) providing a substrate;

(ii) depositing semiconductor layers that comprise at least one absorber layer and at least one doped-window-layer, wherein the doped window layer comprises at least two-sub-window-layers deposited under desirable deposition conditions; and,

(iii) depositing a layer of transparent conducting oxide next to the doped-window-layer but not in direct contact with the absorber layer.

18. The method of claim 17, in which the first sub-window-layer is adjacent to the absorber layer and is deposited under conditions which achieve a desirable junction with the absorber layer; and in which the second sub-window-layer is adjacent the first sub-window-layer but not directly in contact with the absorber-layer and is deposited under conditions which achieve high optical transmission.

19. The method of claim 18, further including depositing the doped window layer before deposition of the semiconductor absorber layer.

20. The method of claim 18, further including depositing the doped window layer after deposition of the semiconductor absorber layer.

21. The method of claim 18, wherein the absorber layer contains silicon and germanium and during the absorber layer deposition an optimized ratio of germane-containing gas and silicon-containing gas provides a Ge content suitable for forming a high efficiency single-junction solar cell.

22. The method of claim 18, wherein the first and second sub-window-layers are deposited by a vapor phase deposition process.

23. The method of claim 22, wherein the vapor phase deposition process comprises plasma enhanced chemical vapor deposition.

24. The method of claim 23, in which the plasma enhanced chemical vapor deposition comprises radio frequency plasma enhanced chemical vapor deposition.

25. The method of claim 24, wherein the first and second window-layers silicon-containing material are selected from the group consisting of a-Si:H, a-$Si_{1-x}C_x$:H, a-$Si_{1-x}Ge_x$:H, nc-Si:H, nc-$Si_{1-x}C_x$:H, nc-$Si_{1-x}Ge_x$:H, μc-Si:H, μc-$Si_{1-x}C_x$:H, μc-$Si_{1-x}Ge_x$:H,as well as the mixture and combination of the above

26. The method of claim 25, wherein the plasma enhanced chemical vapor deposition is by at least one of the following: cathodic direct current glow discharge, anodic direct current glow discharge, radio frequency glow discharge, very high frequency (VHF) glow discharge, alternate current glow discharge, or microwave glow discharge.

27. The solar cell of claim 8 , wherein the first sub-p-layer is deposited at about 140°C.

28. The solar cell of claim 8, wherein the second sub-p-layer has a transparency greater than the transparency of the first sub-p-layer.

29. The solar cell of claim 28, wherein the second sub-p-layer is deposited at a temperature sufficient low to provide acceptable transparency.

30. The solar cell of claim 29, wherein the second sub-p-layer is deposited at or below a temperature of about 70°C.

31. A novel photovoltaic solar cell comprising:

at least one n-type layer,

at least one i-type layer, and

at least two sub-p-layers, wherein first sub-p-layer is deposited at a desired first temperature on the i-type layer, and

a second sub-p-layer is deposited on the first sub-p-layer at a desired second temperature which is lower than the first temperature at which the first sub-p-layer is deposited.

32. The solar cell of claim 31, wherein the first sub-p-layer is deposited on the i-type layer at a temperature sufficiently high to form a good junction with the i-layer.

33. The solar cell of claim 32, wherein the first sub-p-layer is deposited at about 140°C.

34. The solar cell of claim 31, wherein the second sub-p-layer has a transparency greater than the transparency of the first sub-p-layer.

35. The solar cell of claim 34, wherein the second sub-p-layer is deposited at a temperature sufficient low to provide acceptable transparency.

36. The solar cell of claim 35, wherein the second sub-p-layer is deposited at or below a temperature of about 70°C.

37. The solar cell of claim 31, wherein the first sub-p-layer has a thickness in the range of about 1 nm to about 4 nm and the second sub-p-layer has a temperature in the range of about 5nm to about 20nm.

38. The solar cell of claim 31, wherein the first sub-p-layer is thinner than the second sub-p-layer.

39. The solar cell of claim 31, having a conversion efficiency of about 10% or greater.

40. The solar cell of claim 31, further comprising a substrate such as a glass, metal or plastic.

41. The solar cell of claim 40, further comprising a suitable transparent conductive oxide layer adjacent the second sub-p-layer.

42. The solar cell of claim 41, wherein the transparent conductive oxide layer comprises indium-tin-oxide (ITO) deposited at a temperature sufficiently low to avoid damaging the sub-p-layers.

43. The solar cell of claim 31, further comprising an encapsulation layer overlaying the cell to provide a substantially airtight and watertight protective barrier against moisture and contaminants.

44. The solar cell of claim 31, further comprising a buffer semi-conductor layer between the n-layer and the i-layer and between the i-layer and the first sub-p-layer.

45. The solar cell of claim 31, wherein the first and second layers comprise an amorphous silicon-containing material.

46. The solar cell of claim 45, wherein the i-layer comprises amorphous silicon germanium.

47. The solar cell of claim 46, wherein the n-layer comprises amorphous silicon.

48. A method for manufacturing a solar cell comprising the steps of

(i) providing a substrate;

(ii) depositing a layer of n-type semi-conductor on the substrate at a temperature sufficiently low to avoid damage or melting the substrate;

(iii) depositing an i-layer on the n-layer at a temperature sufficiently low to avoid melting or damaging the n-layer;

(iv) depositing a first sub-p-layer on the i-layer at a temperature sufficiently high to form a good junction with the i-layer; and

(v) depositing a second sub-p-layer on the first sub-p-layer at a temperature lower than the first temperature at which the first sub-p-layer is deposited.

49. The method of claim 48, further including depositing a layer of a transparent conductive oxide on the second p-layer.

50. The method of claim 49, wherein a current collection layer is deposited onto the substrate prior to deposition of the n-layer onto the substrate.

51. The method of claim 48, wherein during the i-layer deposition an optimized GeH_4 to Si_2H_6 ratio provides a Ge content suitable for forming a high efficiency single-junction solar cell.

52. The method of claim 51, wherein an optimized level of hydrogen dilution is used to form the i-layer.

53. The method of claim 52, wherein the substrate comprises glass or metal including aluminum, bismuth, iron, niobium, titanium or steel.

54. The method of claim 48, wherein the first and second sub-p-layers are deposited by a chemical vapor deposition process.

55. The method of claim 54, wherein the chemical vapor deposition process comprises plasma enhanced chemical vapor deposition.

56. The method of claim 55, in which the plasma enhanced chemical vapor deposition comprises radio frequency plasma enhanced chemical vapor deposition.

57. The method of claim 56, wherein the first and second p-layers amorphous silicon-containing material selected from the group consisting of hydrogenated amorphous silicon, hydrogenated amorphous carbon, and hydrogenated amorphous silicon germanium.

58. The method of claim 57, wherein the i-layer comprises hydrogenated amorphous silicon germanium having a bandgap ranging from about 1.4 e-V to 1.6 e-V and wherein the first and second sub p-layers comprise amorphous silicon with a bandgap of 1.4 e-V.

59. The method of claim 58, wherein the plasma enhanced chemical vapor deposition is by at least one of the following: cathodic direct current glow discharge, anodic direct current glow discharge, radio frequency glow discharge, very high frequency (VHF) glow discharge, alternate current glow discharge, or microwave glow discharge at a

pressure ranging from about 0.5 to about 5 TORR with a dilution ratio of dilutant to feedstock (deposition gas) ranging from about 5:1 to about 200:1.

60. A method for manufacturing a solar cell comprising the steps of:

(i) providing a transparent substrate;

(ii) depositing a transparent conducting oxide layer on the substrate;

(iii) depositing a second sub-p-layer on the substrate at a temperature relatively low for improved transparency of the second sub p-layer;

(iv) depositing a first sub-p-layer on the second sub-p-layer at a relatively higher temperature to form a good junction with an i-layer to be deposited thereon;

(v) depositing the i-layer on the first sub-p-layer at a temperature sufficiently low to avoid melting or damaging the p-layer; and

(vi) depositing a layer of n-type semi-conductor on the substrate at a temperature sufficiently low to avoid damage or melting the p and i-layers.

61. The method of claim 60, wherein during the i-layer deposition an optimized GeH_4 to Si_2H_6 ratio provides a Ge content suitable for forming a high efficiency single-junction solar cell.

62. The method of claim 61, wherein an optimized level of hydrogen dilution is used to form the i-layer.

63. The method of claim 62, wherein the substrate comprises glass or plastic.

64. The method of claim 63, wherein the first and second sub-p-layers are deposited by a chemical vapor deposition process.

65. The method of claim 64, wherein the chemical vapor deposition process comprises plasma enhanced chemical vapor deposition.

66. The method of claim 65, in which the plasma enhanced chemical vapor deposition comprises radio frequency plasma enhanced chemical vapor deposition.

67. The method of claim 66, wherein the first and second p-layers amorphous silicon-containing material selected from the group consisting of hydrogenated amorphous silicon, hydrogenated amorphous carbon, and hydrogenated amorphous silicon germanium.

68. The method of claim 67, wherein the i-layer comprises hydrogenated amorphous silicon germanium having a bandgap ranging from about 1.4 e-V to 1.6 e-V and wherein the first and second sub p-layers comprise amorphous silicon with a bandgap of around 1.6 e-V.

69. The method of claim 68, wherein the plasma enhanced chemical vapor deposition is by at least one of the following: cathodic direct current glow discharge, anodic direct current glow discharge, radio frequency glow discharge, very high frequency (VHF) glow discharge, alternate current glow discharge, or microwave glow discharge at a pressure ranging from about 0.5 to about 5 TORR with a dilution ratio of dilutant to feedstock (deposition gas) ranging from about 5:1 to about 200:1.

70. The solar cell of claim 3, wherein the photovoltaic cell uses intrinsic semiconductor materials $a\text{-}Si_{(1-x)}Ge_x{:}H$ with minimal light-induced

degradation and appropriate bandgap to achieve high conversion efficiency for single-junction solar cells.

71. The solar celll of Claim 70, wherein x is around 0.1 to 0.3 for high-efficiency single-junction solar cell.

72. The solar cell of Claim 4, wherein the doped window layer is deposited under conditions that continuously changed from that of first sub-window-layer to that of the second sub-window-layer.

73. The solar cell of claim 4 wherein heavily doped interface layer, with doping level greater than the bulk of the n-layer, is used between the n-layer the a TCO layer.

74. The solar cell of claim 4 wherein a heavily doped p-type interface layer, with a doping level greater than the bulk of p-type doped layer, is used between the p-layer and the TCO layer.